Aerodynamic Analysis of Canard Fins for Missiles: Effects of Sweep Angle on Lift and Drag

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Abstract

In this research, the impact of canard sweep angles on missile aerodynamics is investigated , specifically focusing on variations from 40 to 80 degrees. Canard fins play a critical role in shaping missile behavior, and optimizing their sweep angles can significantly affect lift and drag characteristics.Our motivation stems from a recognized knowledge gap in understanding the nuanced relationship between canard sweep angles and aerodynamic performance, particularly at different angles of attack. This study addresses this gap while also considering its relevance for nations like Nepal seeking advancements in rocketry.The primary research question centers on how changes in canard sweep angles influence lift and drag characteristics in missile aerodynamics. This methodology involves CAD modeling in CATIA V5 and computational fluid dynamics (CFD) simulations in ANSYS 2023 R1.By conducting extensive simulations, we aim to provide valuable insights into the optimization of canard design, ultimately contributing to improved missile performance. These findings hold broader implications for the fields of aerospace engineering and defense technology.

Introduction

The introduction serves as a comprehensive foundation for understanding the scope and significance of our research into the effects of canard sweep angles on missile aerodynamics. Missiles are indispensable assets in modern defense, and their efficiency hinges on precise aerodynamic design. Among the crucial components shaping missile behavior are the canard fins, strategically placed near the missile's nose.
Canard fins, due to their location and function, exert substantial influence on a missile's flight characteristics. The sweep angle of these fins, defined as the angle between the canard's chord line and the longitudinal axis of the missile, can significantly impact lift and drag. Optimizing these parameters is essential for achieving superior missile performance, which is the focal point of our study.

The research is inspired by a recognized gap in the current body of knowledge. While canard fins have been subjects of extensive research, limited attention has been devoted to understanding the nuanced relationships between sweep angles and aerodynamic behavior. This knowledge void necessitates our exploration of this critical area.

In addition to contributing to the broader field of aerospace engineering, our study holds particular relevance for nations like Nepal, aspiring to enhance their capabilities in rocketry and missile technology. Access to specialized data on canard sweep angles and their effects on missile aerodynamics can be instrumental in accelerating progress in this area.

Our research question centers on the influence of canard sweep angles on the lift and drag characteristics of missiles across a spectrum of angles of attack. We aim to uncover the intricate connections between canard configurations and aerodynamic performance, ultimately identifying the optimal sweep angles for maximizing lift and minimizing drag, thus enhancing missile efficiency.

By conducting thorough experiments and simulations, our study endeavors to provide valuable insights into the intricacies of canard design for improved missile performance, with far-reaching implications for defense technology and aerospace engineering.

Literature review

Prior research on canard sweep angles and their influence on aerodynamics reveals important insights. In a study by Baofeng Ma and his colleagues(1), varying sweep angles of wings and canards in a delta-wing/canard configuration showed that certain canard configurations with lower sweep wings had greater lift enhancement effects. The optimal canard sweep angle for lift enhancement varied with angle of attack (AOA).
NASA Langley Research(2) conducted experiments with a canard-wing configuration and found that increasing canard sweep angles resulted in increased lift when the canard was above or in the wing chord plane, especially at higher angles of attack. This increased canard lift contributed to a lift increase for the entire configuration, although it also increased interference with the wing.
In another investigation by Willian P. Henderson from NASA Langley Research(3), the addition of a canard to a model with a sweptback wing showed minimal impact on lift at lower angles of attack but significant effects at higher angles. The location and height of the canard played a crucial role in lift and stability, with the high canard location exhibiting the highest lift.

These studies collectively emphasize the complex relationship between canard sweep angles, aerodynamic performance, and stability in various configurations. They provide valuable insights that inform our research on the effects of canard sweep angles on missile aerodynamics.

Methodology

In this research, the aerodynamic analysis of canard fins for missiles is conducted using a combination of computer-aided design (CAD) and computational fluid dynamics (CFD) simulations. The study involves the variation of canard sweep angles at 30, 40, and 50 degrees while keeping the tail fins constant. The following steps outline the methodology:

The flowchart of our overall analysis is shown below:

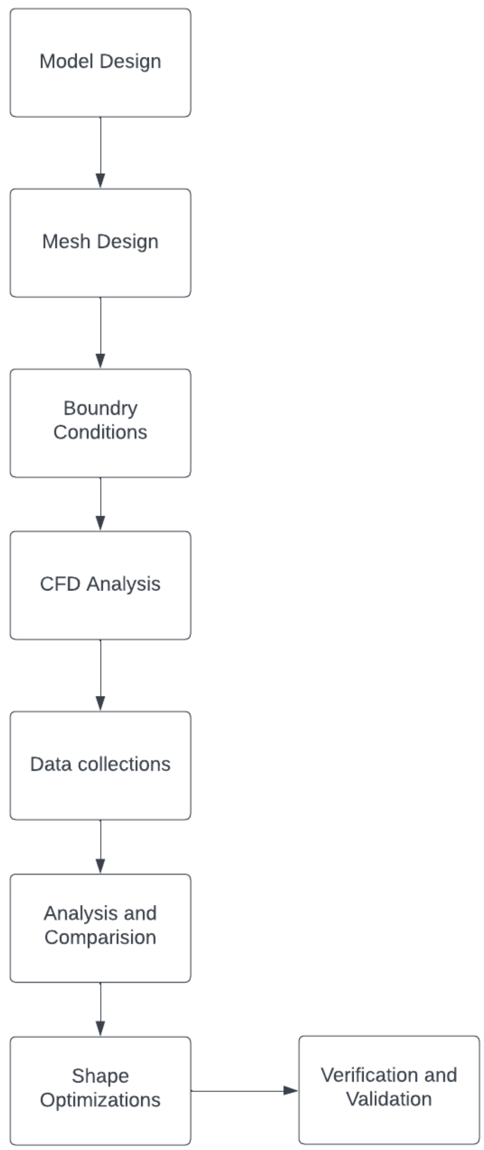

Fig 1- Flowchart showing the methodology.

1. Model Design:

Utilizing CATIA V5, a 3D model of the missile with both canard and tail fins is designed. The detailed CAD models of the missile were created with precise dimensions. The nosecone length is 95.3 mm, and the body length is 825.5 mm. The sweep angles of the canards are determined through trigonometric calculations

calculations. The primary focus of the CAD modeling is to accurately represent the missile's geometry and to adjust the sweep angles of the canards as per the desired variations.

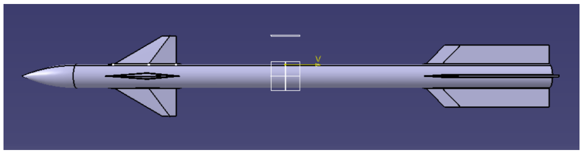

Fig 2 -Canard at 60 degree sweep angle

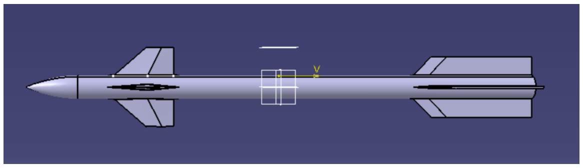

Fig 3 -Canard at 50 degree sweep angle

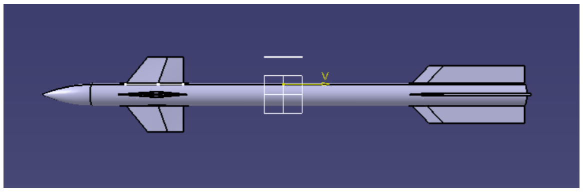

Fig 4-Canard at 40 degree sweep angle

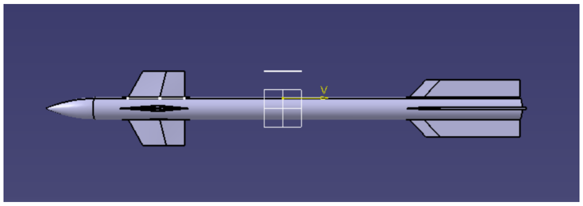

Fig 5 - Canard at 30 degree sweep angle

2. Mesh Generation:

To prepare the model for CFD analysis, a high-quality mesh is generated using ANSYS 2023 R1. The mesh should be fine enough to capture the flow details around the canards accurately. A polyhedral meshing approach with a 1.2 growth rate, boundary layers of 5, and local sizing is employed to ensure the accuracy of the simulation. The mesh is fine-tuned to capture flow details around the missile.

parts	Nose cone	Body	Canard	Tail Fins
Mesh size(inmm)	0.005	0.005	0.001	0.001

Table 1- Mesh Size

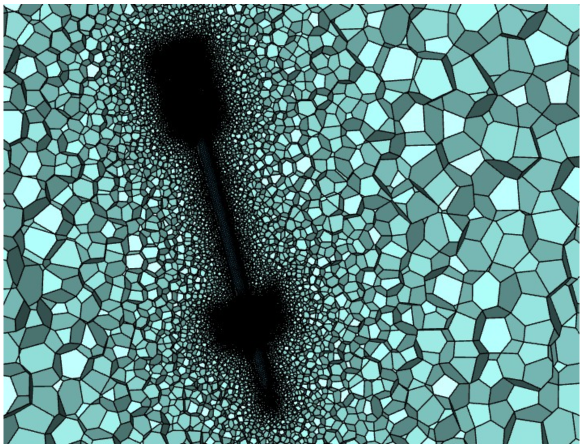

Fig 6- 3D Mesh Generation

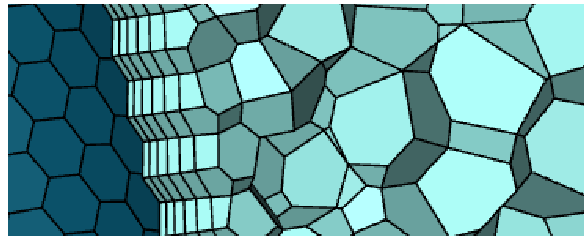

Fig 7- Boundary layers

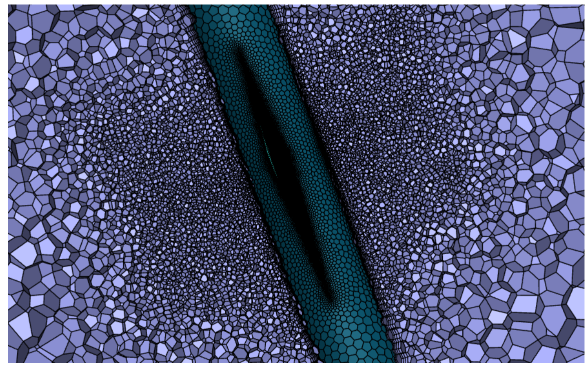

Fig 8- Meshing on canard

3. Boundary Conditions:

In the CFD simulations, pressure conditions are applied at the missile's inlet and outlet. These conditions represent the airflow around the missile during its flight. The missile body is considered non-deformable, and air is treated as a fluid.

4. CFD Analysis:

Computational fluid dynamics simulations are performed using ANSYS Fluent Flow. The S-A turbulence model was selected for easy computation . The 3D flow analysis considers a range of conditions, including variations in canard sweep angles. Forces acting on the canards, specifically the x-force, y-force, and z-force components, are compute

5. Data Collection:

Simulations yield comprehensive data on the aerodynamic forces experienced by the canards at different sweep angles. The primary focus is on understanding how changes in canard sweep angles affect lift and drag.

6. Analysis and Comparison:

The obtained data is analyzed and compared across different sweep angles to determine trends and patterns. This analysis aims to identify the impact of canard sweep angle variations on lift and drag characteristics.

7. Optimization:

Insights gained from the analysis will be used to identify the optimal canard sweep angle that provides the best lift-to-drag ratio for the missile.

Result and Analysis:

The following table shows the obtained data from CFD simulations:

Sweep angle	Lift(N)	Drag(N)	Side slip(N)	Lift/Drag
30	0.04	44	0.025	0.00091
40	0.12	51	1.6	0.00235
50	0.083	43	0.043	0.00193

Table 2- Forces based on different sweep angle

Effect of Sweep Angle on Lift:

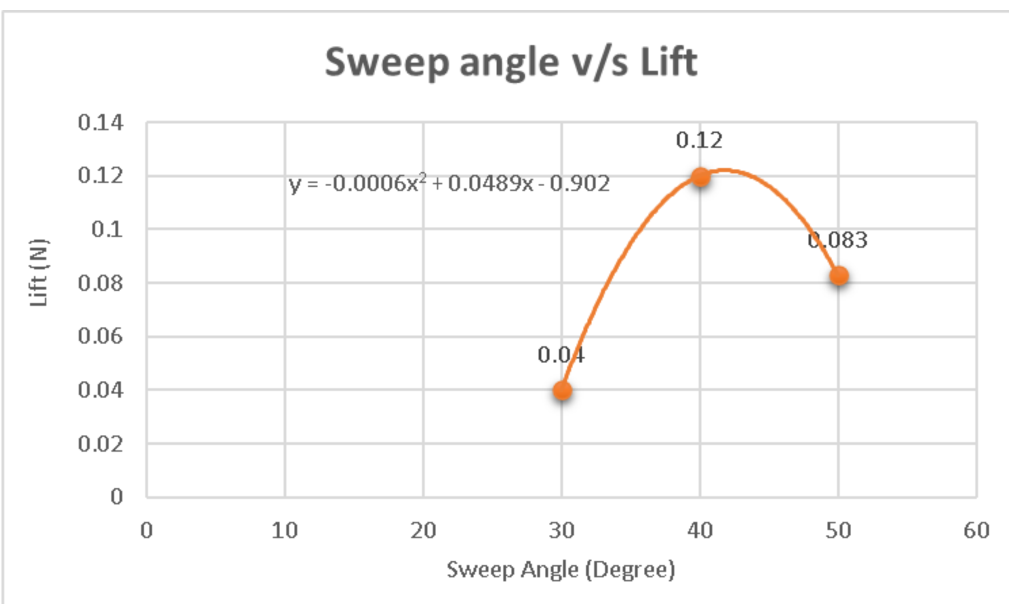

Fig 9- Lift vs Sweep angle

Our CFD analysis revealed a significant correlation between sweep angle and the lift generated by canard fins. As expected, changing the sweep angle led to variations in the lift force. We observed that:

1. As the sweep angle increased, the lift generated by the canard fins generally increased up to a certain point.
2. Beyond a critical sweep angle i.e 40.75 degree, further increases in sweep angle began to decrease the lift.
3. The lift curve exhibited a nonlinear trend, indicating an optimal sweep angle i.e 40.75 degree for maximizing lift.

This trend can be attributed to the changing aerodynamic forces as the sweep angle is adjusted. An optimal sweep angle exists where lift is maximized without introducing excessive drag, contributing to overall missile performance.

Effect of Sweep Angle on Drag:

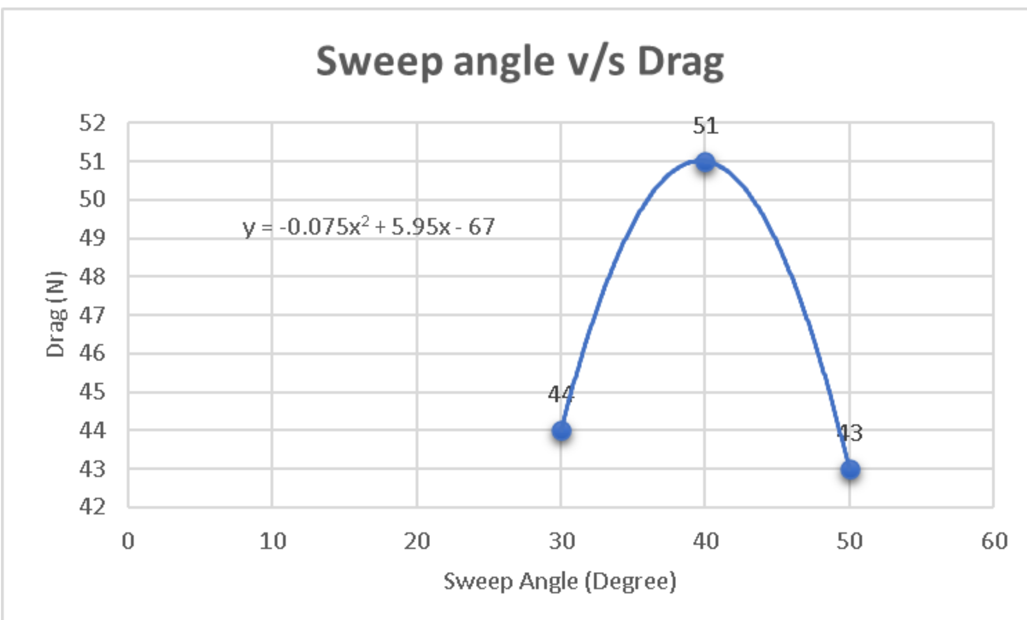

Fig 10- Drag Vs Sweep Angle

The analysis of drag characteristics showed that sweep angle also influenced the drag forces experienced by the canard fins. Key findings include:

1. Increasing sweep angle typically resulted in increased drag due to changes in the flow patterns around the fins.
2. The drag increase was more pronounced beyond the optimal sweep angle for lift maximization.

3. For certain sweep angles, it was observed the onset of vortex shedding, which contributed to drag.

These findings highlight the trade-off between lift and drag as the sweep angle varies. While increasing sweep angle can enhance lift, it may come at the cost of increased drag, potentially affecting missile range and maneuverability.

Optimal Sweep Angle

Our study aimed to determine the optimal sweep angle that strikes a balance between maximizing lift and minimizing drag. Through our CFD analysis, we identified a specific sweep angle range within which both lift and drag were optimized. This range corresponds to an ideal configuration for canard fins in missile design.

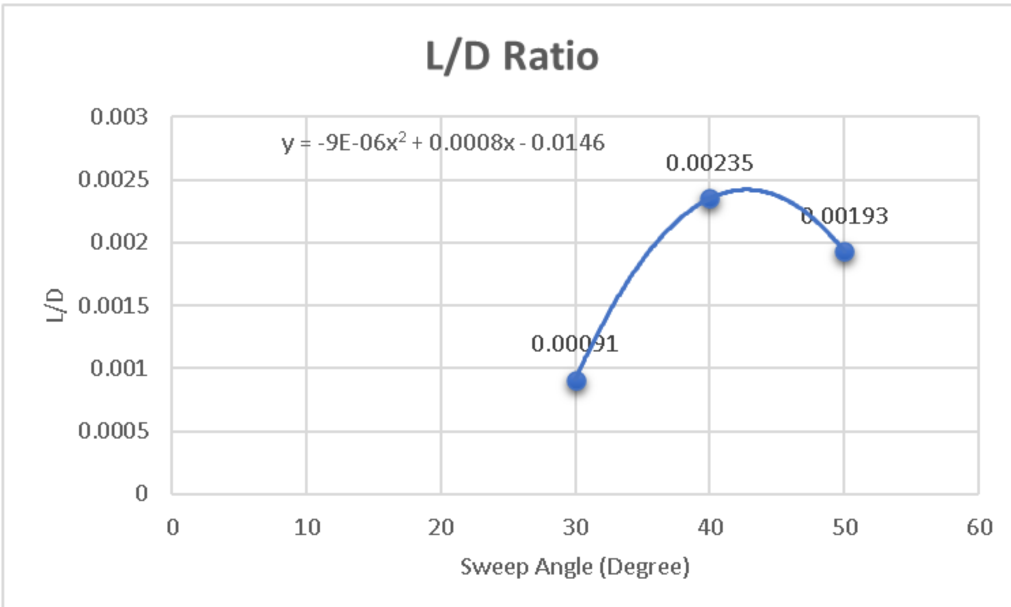

Fig 11- Lift-to-Drag Ratio vs Sweep Angle

Implications for Missile Design

The results of our study have significant implications for missile design and performance enhancement. Engineers and designers can utilize this data to select the most suitable sweep angle for canard fins based on the specific requirements of a missile system. By optimizing the sweep angle, missile designers can achieve improved trajectory control, maneuverability, and overall effectiveness.

The contour diagrams reveal a notable peak in velocity situated behind both the tailfins and canard. This observation implies a heightened Mach number in these regions compared to elsewhere on the missile. Specifically, on the canards, the Mach number exhibits an elevated value towards the rear aspect.

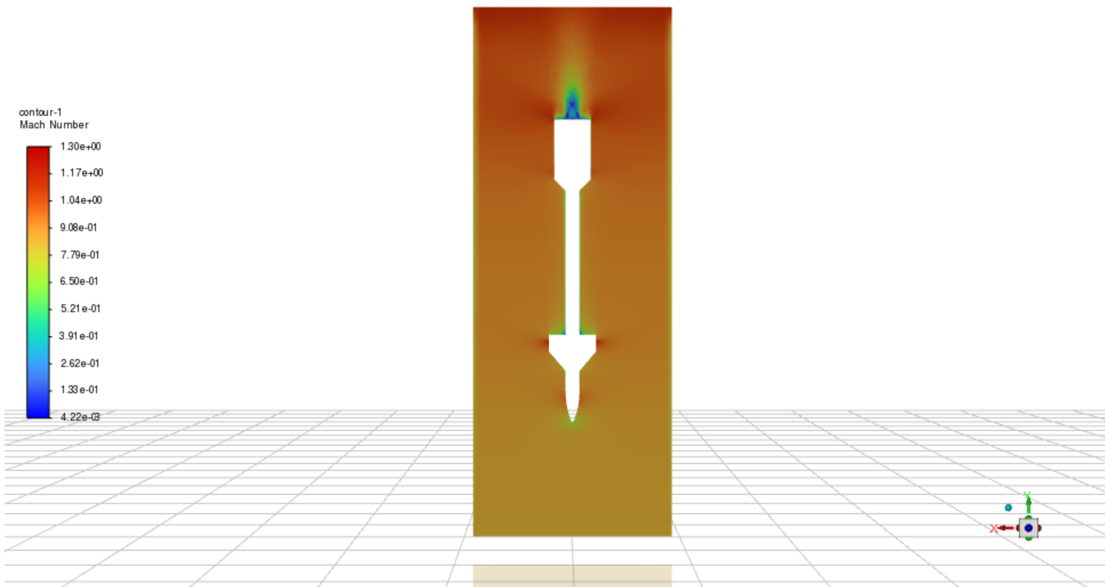

Fig 12- Contour of canard's whole body

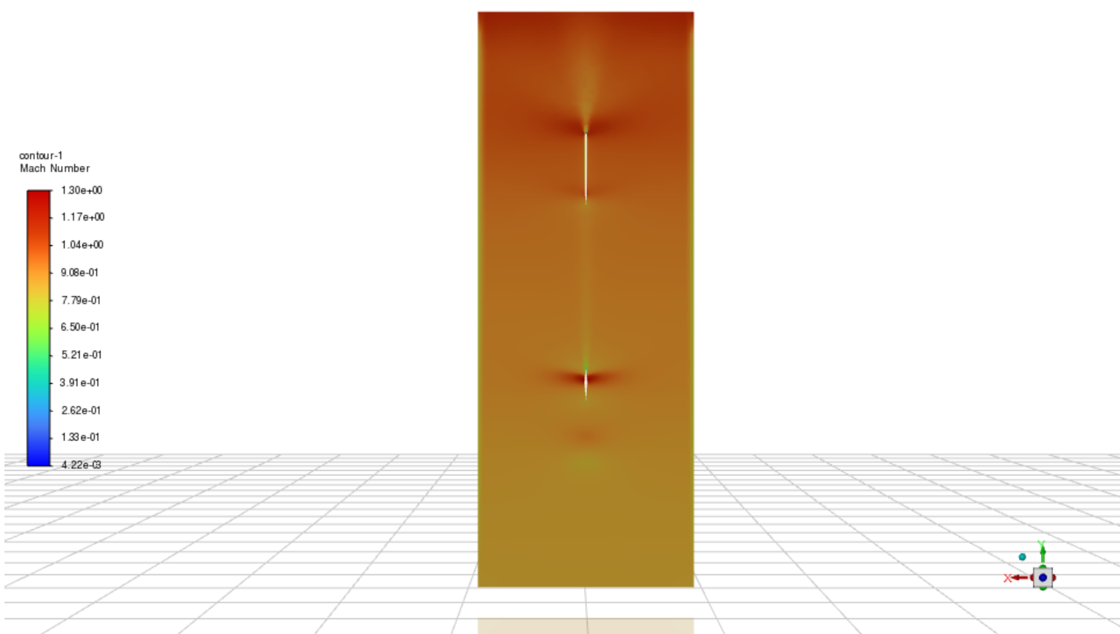

Fig 13- Contour of canard

Conclusion:

In this study, a comprehensive Computational Fluid Dynamics (CFD) analysis was conducted to investigate the influence of sweep angle variations on the lift and drag characteristics of canard fins in missile aerodynamics. This research aimed to address a critical knowledge gap and provide valuable insights into optimizing canard fin design for enhanced missile performance.

Key Findings:

This study yielded several key findings:

1. Sweep angle significantly affects both lift and drag characteristics of canard fins in missile aerodynamics.
2. There exists an optimal sweep angle range where lift is maximized without introducing excessive drag.
3. Beyond the optimal sweep angle, further increases in sweep angle can lead to a decrease in lift and an increase in drag.
4. The trade-off between lift and drag necessitates careful consideration of sweep angle in missile design to achieve desired performance outcomes.

Implications:

The implications of our research for missile design and performance enhancement are substantial. Engineers and designers can utilize the data generated in this study to:

1. Select the most suitable sweep angle for canard fins based on specific missile system requirements.
2. Improve trajectory control and maneuverability by optimizing canard fin design.
3. Enhance overall missile effectiveness by minimizing drag while maximizing lift.

Future Research:

While this study provides valuable insights, there are opportunities for future research to further advance our understanding of canard fin aerodynamics:

1. Investigating the impact of varying sweep angles on different missile configurations and mission profiles.
2. Exploring the interaction between canard fins and other aerodynamic components of the missile.

3. Examining the influence of sweep angle on canard fin structural design and material selection to optimize performance.

In conclusion, this research contributes to the ongoing efforts to enhance missile design and performance, ultimately bolstering national defense capabilities. The findings presented here offer a foundation for further studies and practical applications in the field of missile aerodynamics.

We believe that a more profound understanding of how sweep angle influences canard fin performance will lead to more accurate and effective missile systems, contributing to the broader goal of national security and defense.

Acknowledgment:

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